

Lepton Flavor Violation processes in 331 Models

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Abstract

Processes $\tau \rightarrow l\gamma$, $\tau \rightarrow ll\bar{l}$ with $l = e, \mu$ and $\mu(\tau) \rightarrow e(\mu)\gamma$ are evaluated in the framework of a model based on the extended symmetry gauge $SU(3)_c \otimes SU(3)_L \otimes U(1)_Y$ with a leptonic sector consistent of five triplets. Lepton flavor violating processes are allowed at tree level in this model through the new Z' gauge boson. We obtained bounds for the mixing angles in the leptonic sector of the model, considering the experimental measurements of the processes from the BELLE and the BABAR collaborations.

1 Introduction

In the framework of the standard model (SM) of high energy physics there are many unclear issues that require extensions of the theory in the local symmetry and in the particle spectrum. One possible alternative is based on the gauge symmetry $SU(3)_c \otimes SU(3)_L \otimes U(1)_X$, known as 331 models[1]. These models can explain why there are three fermionic families through the chiral anomaly cancellation condition considering and the number of colors in QCD. On the other hand, the models based on the 331 symmetry are built in such a way that the couplings of the quarks with the new neutral Z' boson are not universal in the interaction basis, making them not diagonal in the mass eigenstates basis and yielding to flavor changing neutral currents (FCNC) at tree level [2]. This is a special feature of the 331 models, due to one quark family being in a different representation of the gauge group to the other two families, in order to satisfy the chiral anomaly cancellation condition. It is worth mentioning that in some 331 models there are not only contributions from the left handed neutral current but also from the right handed neutral currents. There are many studies of these new FCNC in the quark sector where are different observables in the up and down sectors that constrain such kind of processes. In contrast, there are not so many analysis in the leptonic sector, where leptonic flavor violation (LFV) processes at tree level are present.

In particular, LFV processes such as $\tau \rightarrow l^- l^+ l^-$ with $l = e, \mu$, have been discussed in the framework of the minimal supersymmetric standard model, Little Higgs models, left-right symmetry models and many other extensions of the SM [3]. Some of these models predict branching fractions for $\tau \rightarrow l^- l^+ l^-$ of the order of 10^{-7} which could be detected in future experiments. Recently, the MEGA and the SINDRUM collaborations have reported new bounds on LFV processes; MEGA has

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reported $BR(\mu \rightarrow e\gamma) < 1.2 \times 10^{-11}$ [4] and SINDRUM $BR(\mu \rightarrow 3e) < 1 \times 10^{-12}$ [5]. These bounds together with the bounds on $\tau \rightarrow l\gamma$, $\tau \rightarrow lll$ with $l = e, \mu$ and $\mu(\tau) \rightarrow e(\mu)\gamma$ coming from the BELLE and the BABAR experiments are a phenomenological source to explore the origin of the mixing in the leptonic sector.

As it was already mentioned, one set of possible extensions of the SM are models based on the 331 symmetry where LFV processes can be explored and this would be the focus of this paper. Different 331 models can be built [6], they can be distinguished using the electric charge of the new particles introduced in the spectrum and the structure of the scalar sector, where models without exotic charges will be considered. In general, the 331 models are classified depending on how they cancel the chiral anomalies: there are two models that cancel out the anomalies requiring just one family and eight models where the three families are required. In the three family models, there are four models where the leptons are treated identically, two of them treat two quark generations identically and finally, there are two models where all the lepton generations are treated differently [6]. There is one of these 331 models where the leptonic sector is described by five left handed leptonic triplets in different representations of the $SU(3)_L$ gauge group. Using these five leptonic representations it is possible to obtain models where the three known leptons coupled to the Z' boson are very different with respect to the new ones. We concentrate on these models in this work, studying the LFV processes and obtain constraints on the leptonic mixing matrix. In the next section we are going to present the main features of the model under consideration and then we focus on the LFV processes, namely $\tau \rightarrow l^- l^+ l^-$ with $l = e, \mu$, and $\mu \rightarrow 3e$, $\mu \rightarrow e\gamma$ and $\tau \rightarrow \mu(e)\gamma$.

2 The Model 331

The model considered is based on the local gauge symmetry $SU(3)_C \otimes SU(3)_L \otimes U(1)_X$ (331), where it is common to write the electric charge generator as a linear combination of the diagonal generators of the group:

$$Q = T_3 + \beta T_8 + X, \quad (1)$$

where the parameter β is used to label the particular type of 331 model considered. For constructing the model we choose $\beta = -1/\sqrt{3}$, which corresponds to models where the new fields in the spectra do not have exotic electric charges.

The quark content of this model is described by

$$\begin{aligned} q_{mL} = \begin{pmatrix} u_m \\ -d_m \\ B_m \end{pmatrix}_L &\sim (3^*, 3, 0), & q_{3L} = \begin{pmatrix} u_3 \\ d_3 \\ T_3 \end{pmatrix}_L &\sim (3, 3, 1/3) \\ d^c \sim (3^*, 1, 1/3), & u^c \sim (3^*, 1, -2/3), & B_m^c \sim (3^*, 1, 1/3), & T^c \sim (3^*, 1, -2/3), \end{aligned} \quad (2)$$

where $m = 1, 2$ and their assigned quantum numbers of $SU(3)_C \otimes SU(3)_L \otimes U(1)_X$ are shown in the parenthesis.

For the leptonic spectrum we use

$$\begin{aligned}
\Psi_{nL} &= \begin{pmatrix} e_n^- \\ \nu_n \\ N_n^0 \end{pmatrix}_L \sim (1, 3^*, -1/3), & \Psi_L &= \begin{pmatrix} \nu_1 \\ e_1^- \\ E_1^- \end{pmatrix}_L \sim (1, 3, -2/3), \\
\Psi_{4L} &= \begin{pmatrix} E_2^- \\ N_3^0 \\ N_4^0 \end{pmatrix}_L \sim (1, 3^*, -1/3), & \Psi_{5L} &= \begin{pmatrix} N_5^0 \\ E_2^+ \\ e_3^+ \end{pmatrix}_L \sim (1, 3^*, 2/3), \\
e_n^c &\sim (1, 1, 1), & e_3^c &\sim (1, 1, 1), & E_1^c &\sim (1, 1, 1), & E_2^c &\sim (1, 1, 1),
\end{aligned} \tag{3}$$

with $n = 2, 3$. The five leptonic triplets together with the quark content insures cancellation of chiral anomalies. Furthermore, notice that with this proposed assemble for the leptonic sector, there is only one of the triplets that is not written in the adjoint representation of $SU(3)_L$ and it contains one of the standard lepton families of the SM.

On the other hand, in 331 models without exotic charges, the gauge bosons of the $SU(3)_L$ which transform according to the adjoint representation, are given by

$$\mathbf{W}_\mu = W_\mu^a \frac{\lambda^a}{2} = \frac{1}{2} \begin{pmatrix} W_\mu^3 + \frac{1}{\sqrt{3}} W_\mu^8 & \sqrt{2} W_\mu^+ & \sqrt{2} K_{1\mu}^0 \\ \sqrt{2} W_\mu^- & -W_\mu^3 + \frac{1}{\sqrt{3}} W_\mu^8 & \sqrt{2} \bar{K}_{2\mu}^+ \\ \sqrt{2} \bar{K}_{1\mu}^0 & \sqrt{2} K_{2\mu}^- & -\frac{2}{\sqrt{3}} W_\mu^8 \end{pmatrix}, \tag{4}$$

where λ^a are the Gell-Mann matrices for the considered group. The gauge boson field B_μ is associated with the $U(1)_X$ group which is a singlet under $SU(3)_L$ and it does not have electric charge. Once the gauge boson sector is identified then the bosons of the neutral sector (W^3, W^8, B) are rotated to get the new neutral gauge bosons A, Z and Z' :

$$\begin{pmatrix} A \\ Z \\ Z' \end{pmatrix} = \begin{pmatrix} S_W & -S_W/\sqrt{3} & C_W \sqrt{1 - T_W^2/3} \\ C_W & S_W T_W/\sqrt{3} & -S_W \sqrt{1 - T_W^2/3} \\ 0 & -\sqrt{1 - T_W^2/3} & -T_W/\sqrt{3} \end{pmatrix} \begin{pmatrix} W^3 \\ W^8 \\ B \end{pmatrix}, \tag{5}$$

where θ_W is the Weinberg's angle defined by $T_W = \tan \theta_W = g'/\sqrt{g^2 + g'^2/3}$, with g and g' the coupling constants of the $SU(3)_L$ and $U(1)_X$ groups respectively ($S_W = \sin \theta_W$, $C_W = \cos \theta_W$). In this new basis, the photon A_μ is the gauge boson associated to the charge generator Q while the Z_μ boson can be identified as the usual Z gauge boson of the SM. Scalar states in these models in general can be considered as real fields, therefore the neutral heavy state $\sqrt{2} \text{Im}K$ decouples from the other neutral bosons, becoming an exact mass eigenstate. However, the vector bosons Z, Z' and $\sqrt{2} \text{Re}K$ in general mix [6]. Then, one can rotate to the mass eigenstate basis, say Z_1, Z_2, Z_3 (where Z_1 is the ordinary gauge boson seen in high energy experiments) through an orthogonal mixing matrix R :

$$\begin{pmatrix} Z \\ Z' \\ \sqrt{2} \text{Re}K \end{pmatrix} = R \begin{pmatrix} Z_1 \\ Z_2 \\ Z_3 \end{pmatrix}. \tag{6}$$

For the purpose of this work we will assume that $\text{Re}K$ does not mix with the Z and Z' bosons.

Our main aim concerns the leptonic phenomenology and therefore only the leptonic sector will

be addressed. The Lagrangian for the neutral currents in this sector is

$$\mathcal{L}_{NC} = - \sum_{\ell} \left[g S_W A_{\mu} \left\{ \bar{\ell}^0 \gamma_{\mu} \epsilon_{\ell(L)}^A P_L \ell^0 + \bar{\ell}^0 \gamma_{\mu} \epsilon_{\ell(R)}^A P_R \ell^0 \right\} \right. \quad (7)$$

$$\left. + \frac{g Z^{\mu}}{2 C_W} \left\{ \bar{\ell}^0 \gamma_{\mu} \epsilon_{\ell(L)}^Z P_L \ell^0 + \bar{\ell}^0 \gamma_{\mu} \epsilon_{\ell(R)}^Z P_R \ell^0 \right\} \right. \\ \left. + \frac{g' Z'^{\mu}}{2 \sqrt{3} S_W C_W} \left\{ \bar{\psi}^0 \gamma_{\mu} \epsilon_{\ell(L)}^{Z'} P_L \ell^0 + \bar{\ell}^0 \gamma_{\mu} \epsilon_{\ell(R)}^{Z'} P_R \ell^0 \right\} \right], \quad (8)$$

where ℓ^0 in this notation stands for the charged leptons vector $\ell^{0T} = (e_1^{0-}, e_2^{0-}, e_3^{0-}, E_1^{0-}, E_2^{0-})$. The zero superscript denotes that the fields are in the interaction basis, and the couplings to the neutral bosons are

$$\begin{aligned} \epsilon_{\ell_L}^A &= I_{5 \times 5}, \\ \epsilon_{\ell(R)}^A &= I_{5 \times 5} \\ \epsilon_{\ell_L}^Z &= \text{Diag}(C_{2W}, C_{2W}, C_{2W}, -2S_W^2, C_{2W}), \\ \epsilon_{\ell_R}^Z &= \text{Diag}(-2S_W^2, -2S_W^2, -2S_W^2, -2S_W^2, C_{2W}), \\ \epsilon_{\ell_L}^{Z'} &= \text{Diag}(1, -C_{2W}, -C_{2W}, -C_{2W}, -C_{2W}), \\ \epsilon_{\ell_R}^{Z'} &= \text{Diag}(2S_W^2, 2S_W^2, -C_{2W}, 2S_W^2, 1), \end{aligned} \quad (9)$$

where $C_{2W} = \cos(2\theta_W)$. Notice that the couplings of the standard charged leptons to the photon A_{μ} are universal as well as the couplings to the Z boson. A feature of this model is that the couplings of the standard left handed leptons as well as the right handed leptons to the Z' boson are not universal, due to the fact that one of the lepton triplets is in a different representation to the other two. Since these couplings to the Z' boson are not universal, at least for the standard leptons, when they are rotated to mass eigenstates the obtained mixing matrix will allow LFV at tree level.

A similar procedure in the neutral leptonic sector can be done, $N^{0T} = (\nu_1^0, \nu_2^0, \nu_3^0, N_1^0, N_2^0, N_3^0, N_4^0, N_5^0)$ generating the couplings

$$\begin{aligned} \epsilon_{N_L}^A &= 0 \\ \epsilon_{N_L}^Z &= \text{Diag}(1, 1, 1, 0, 0, 1, 0, -1) \\ \epsilon_{N_L}^{Z'} &= \text{Diag}(1, -C_{2W}, -C_{2W}, 2C_W^2, 2C_W^2, -C_{2W}, 2C_W^2, -1). \end{aligned} \quad (10)$$

Here the couplings of the standard neutrinos to the photon A and Z boson are universal but the couplings of the corresponding leptons to the Z' are not.

It is possible to re-write the neutral current Lagrangian in order to use the formalism presented in reference [8] and generate an effective Lagrangian like

$$\mathcal{L}_{NC}^{eff} = - e J_{em}^{\mu} A_{\mu} - g_1 J^{(1)\mu} Z_{1\mu} - g_2 J^{(2)\mu} Z_{2\mu}, \quad (11)$$

where the currents associated to the gauge Z and Z' bosons are

$$J_{\mu}^{(1)} = \sum_{ij} \bar{\ell}_i^0 \gamma_{\mu} (\epsilon_{\ell_L}^Z P_L + \epsilon_{\ell_R}^Z P_R) \ell_j^0, \quad (12)$$

$$J_{\mu}^{(2)} = \sum_{ij} \bar{\ell}_i^0 \gamma_{\mu} (\epsilon_{\ell_L}^{Z'} P_L + \epsilon_{\ell_R}^{Z'} P_R) \ell_j^0, \quad (13)$$

with $g_1 = g/C_W$. The ℓ_i^0 leptons and the gauge bosons Z_1 and Z_2 are interaction eigenstates and the matrices $\epsilon_{\ell_{L,R}}^Z$ and $\epsilon_{\ell_{L,R}}^{Z'}$ in the charged sector were defined in equation (9). When the fields of the theory are rotated to mass or physical eigenstates the effective Lagrangian for the charged leptons can be finally written as:

$$\mathcal{L}_{\text{eff}} = - \frac{4G_F}{\sqrt{2}} \sum_{ijkl} \sum_{XY} C_{XY}^{ijkl} (\bar{\ell}_i \gamma^\mu P_X \ell_j) (\bar{\ell}_k \gamma_\mu P_Y \ell_l), \quad (14)$$

where X and Y run over the chiralities L, R and indices i, j, k, l over the leptonic families. The coefficients C_{XY}^{ijkl} for the standard leptons, assuming a mixing angle θ between Z and Z' bosons, are given by [8],

$$C_{XY}^{ijkl} = z \rho \left(\frac{g_2}{g_1} \right)^2 B_{ij}^X B_{kl}^Y, \quad (15)$$

where

$$\begin{aligned} \rho &= \frac{m_W^2}{m_Z^2 C_W^2}, \\ z &= \left(\sin^2 \theta + \frac{m_Z^2}{m_{Z'}^2} \cos^2 \theta \right), \\ \left(\frac{g_2}{g_1} \right)^2 &= \frac{1}{3(1 - 4S_W^2)}. \end{aligned} \quad (16)$$

The B^X corresponds to the matrices obtained when the unitary matrices $V_{L,R}^\ell$ are introduced to obtain the mass eigenstates and to diagonalize the Yukawa coupling matrices:

$$B^X = V_X^{\ell\dagger} \epsilon_\ell^{Z'} V_X^\ell. \quad (17)$$

For the matrix V we will use a well accepted Ansatz [7] where

$$V_L^\ell = P \tilde{V} K \quad (18)$$

with $P = \text{diag}(e^{i\phi_1}, 1, e^{i\phi_3})$, $K = \text{diag}(e^{i\alpha_1}, e^{i\alpha_2}, e^{i\alpha_3})$, and the unitary matrix \tilde{V} can be parameterized using three standard mixing angles θ_{12} , θ_{23} and θ_{13} and a phase φ ,

$$\tilde{V} = \begin{pmatrix} c_{12} c_{13} & s_{12} c_{13} & s_{13} e^{-i\varphi} \\ -s_{12} c_{23} - c_{12} s_{23} s_{13} e^{i\varphi} & c_{12} c_{23} - s_{12} s_{23} s_{13} e^{i\varphi} & s_{23} c_{13} \\ s_{12} s_{23} - c_{12} c_{23} s_{13} e^{i\varphi} & -c_{12} s_{23} - s_{12} c_{23} s_{13} e^{i\varphi} & c_{23} c_{13} \end{pmatrix}. \quad (19)$$

Notice that if we are considering only the standard charged leptons, the coupling matrices in ec.9 can be written as

$$\begin{aligned} \epsilon_{\ell_L}^{Z'} &= -(1 - 2S_W^2) \mathbf{I}_{3 \times 3} + 2C_W^2 \text{Diag}(1, 0, 0), \\ \epsilon_{\ell_R}^{Z'} &= 2S_W^2 \mathbf{I}_{3 \times 3} - \text{Diag}(0, 0, 1). \end{aligned} \quad (20)$$

The terms which are proportional to the identity are not contributing to the LFV processes at tree level, while the second term in the above equations does. These equations (20) correspond to the case where the first family is in the adjoint representation. However, if the second family was the chosen one to be in a different representation then the only change is in the second term which is proportional to $\text{Diag}(0, 1, 0)$. Finally, if instead of that the third family was chosen, then again the only change is the position of the entry different from zero in the second term. We should emphasize that the source of LFV in neutral currents mediated by the Z' boson, comes from the non-diagonal elements in the 3×3 matrices $B_{L,R}^\ell$.

Processes	$BR(\times 10^{-8})$ BELLE	$BR(\times 10^{-8})$ BABAR
$\tau^- \rightarrow e^- \gamma$	12	3.3
$\tau^- \rightarrow \mu^- \gamma$	4.5	4.4
$\tau^- \rightarrow e^- e^+ e^-$	2,7	2,9
$\tau^- \rightarrow \mu^- \mu^+ \mu^-$	2,1	3,3
$\tau^- \rightarrow e^- \mu^+ \mu^-$	2,7	3,2
$\tau^- \rightarrow \mu^- e^+ e^-$	1,8	2,2
$\tau^- \rightarrow e^+ \mu^- \mu^-$	1,7	2,6
$\tau^- \rightarrow \mu^+ e^- e^-$	1,5	1,8

Table 1: Experimental data and their bounds from BELLE [9] and BABAR [10]

3 LFV processes

Our next task is to get bounds on the parameters involved in the LFV couplings and it is done considering different LFV processes. Recently, the BELLE [9] and BABAR[10] collaborations have reported measurements of various LFV channels and they have put new bounds on these branching fractions, see table 1. Other channels to consider are $BR(\mu^- \rightarrow e^- \gamma) < 2,4 \times 10^{-12}$ [9] and $BR(\mu^- \rightarrow e^- e^- e^+) < 1,0 \times 10^{-12}$ [9].

In the framework of the model 331 that we presented in section 2, we calculated the decay widths for the different processes that we are going to consider. For the $l_j \rightarrow l_i \gamma$ processes, the decay widths are

$$\Gamma(l_j \rightarrow l_i \gamma) = \frac{\alpha G_F^2 M_j^3}{8\pi^4} \left(\frac{g_2}{g_1} \right)^4 \rho^2 \left[(B^R M_l B^L)_{ij}^2 + (B^L M_l B^R)_{ij}^2 \right], \quad (21)$$

with $i, j = e, \mu, \tau$, and M_l a diagonal mass matrix where the electron mass has been neglected. From table 1, we should also evaluate the decay widths into three charged leptons:

$$\begin{aligned} \Gamma(l_j \rightarrow l_i^- l_i^- l_i^+) &= \frac{G_F^2 M_{l_j}^5}{48\pi^3} \left(\frac{g_2}{g_1} \right)^4 \rho^2 \\ &\times \left[2 |B_{ij}^L B_{ii}^L|^2 + 2 |B_{ij}^R B_{ii}^R|^2 + |B_{ij}^L B_{ii}^R|^2 + |B_{ij}^R B_{ii}^L|^2 \right], \\ \Gamma(l_j \rightarrow l_i^- l_k^- l_l^+) &= \frac{G_F^2 M_{l_j}^5}{48\pi^3} \left(\frac{g_2}{g_1} \right)^4 \rho^2 \\ &\times \left[|B_{ij}^L B_{kl}^L + B_{kj}^L B_{il}^L|^2 + |B_{ij}^R B_{kl}^R + B_{kj}^R B_{il}^R|^2 + |B_{ij}^L B_{kl}^R|^2 + |B_{kj}^L B_{il}^R|^2 \right. \\ &\quad \left. + |B_{ij}^R B_{kl}^L|^2 + |B_{kj}^R B_{il}^L|^2 \right], \end{aligned} \quad (22)$$

where the elements $B_{ij}^{L,R}$ are defined in equation (17) and ρ in equation (16).

In order to do the numerical analysis, we trace back the final parameters which are going to be present in the decay widths, namely the mixing angles θ_{12} , θ_{23} , θ_{13} and the Z' gauge boson mass. There are also phases coming from the V_l matrix. We have found their effect to be negligible and

therefore we have assumed them equal to zero. We are going to consider two cases depending on which leptonic family is in a different representation of $SU(3)_L$: the first or the third leptonic family. We should mention that the option of the second leptonic family in a different representation is completely analogous to the case of the first family, so we do not present that case.

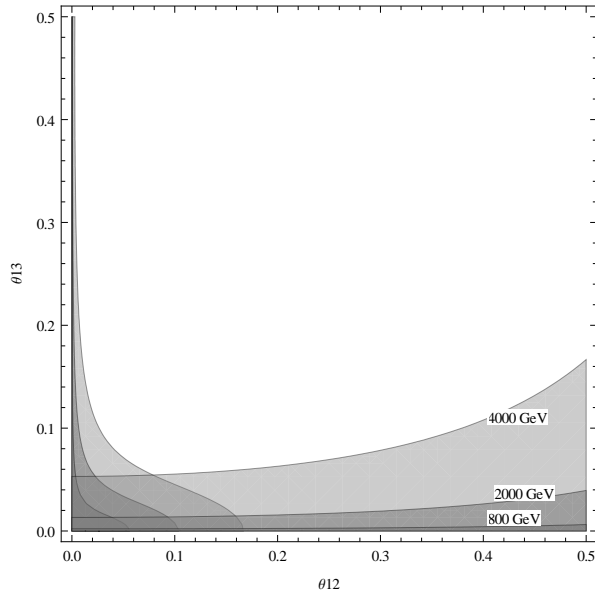


Figure 1: The allowed region from processes $\tau \rightarrow lll$ and $\mu \rightarrow e\gamma$ in the $\theta_{12} - \theta_{13}$ plane using different Z' boson masses (800, 2000, 4000) GeV.

For the case of the first leptonic family in a different representation, the rotation matrix in the charged leptonic sector depends on θ_{12} , θ_{13} and the Z' boson mass, assuming that the phases involved are zero. Now, we use the experimental bounds on the different LFV processes shown in table 1 in order to obtain constraints on the mixing parameters and the Z' boson mass. In figure 1, bounds coming from the six decay widths of τ into three charged leptons are shown in the $\theta_{12} - \theta_{13}$ plane. We have used Z' boson masses of (800, 2000, 4000) GeV. On the other hand, from the process $\tau \rightarrow e\gamma$, it is observed that for $\theta_{12} < 0.1$ the mixing angle θ_{13} could be up to (0.08, 0.14, 0.2) for the Z' boson masses $m_{Z'} = (800, 2000, 4000)$ GeV. Finally, the processes $\mu \rightarrow eee$ and $\tau \rightarrow \mu\gamma$ are not generating stronger bounds on the parameters than the ones mentioned previously.

4 Conclusions

In this work, we have addressed the LFV processes in a model based on the 331 symmetry where the leptonic sector is described by five left handed leptonic triplets in different representations of the $SU(3)_L$ gauge group. Here, the couplings of the new neutral Z' boson with the usual leptons are not universal. This feature is due to one of the lepton triplets being in a different representation than the other two, which leads to LFV at tree level once they are rotated to mass eigenstates. We have considered some LFV processes which have been measured by the BELLE and the BABAR collaborations: $\tau \rightarrow 3l$, $\tau \rightarrow l\gamma$, $\mu \rightarrow e\gamma$ and $\mu \rightarrow 3e$ (see table 1). The analysis was done considering two cases depending on which leptonic family is in the different representation of $SU(3)_L$ in the 331

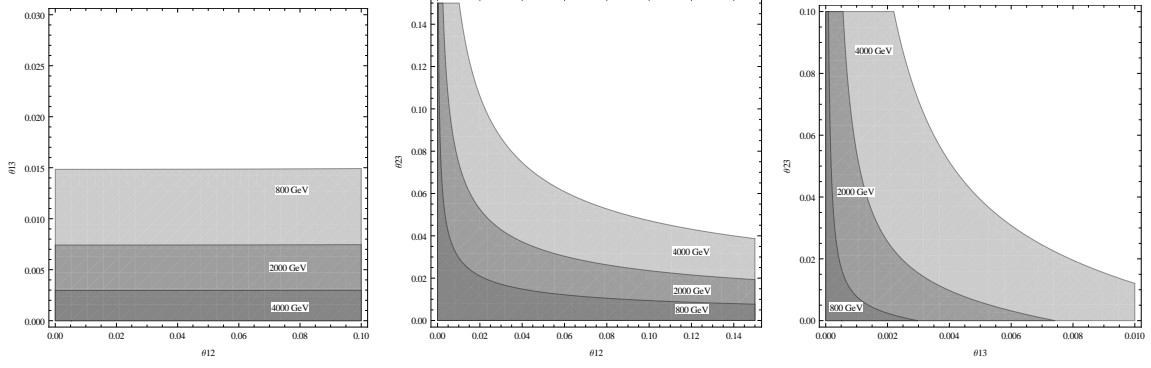


Figure 2: Bounds coming from the $\mu \rightarrow e\gamma$ process in the different planes such that the third mixing angle is set to zero for $m_{Z'}(800, 2000, 4000\text{GeV})$.

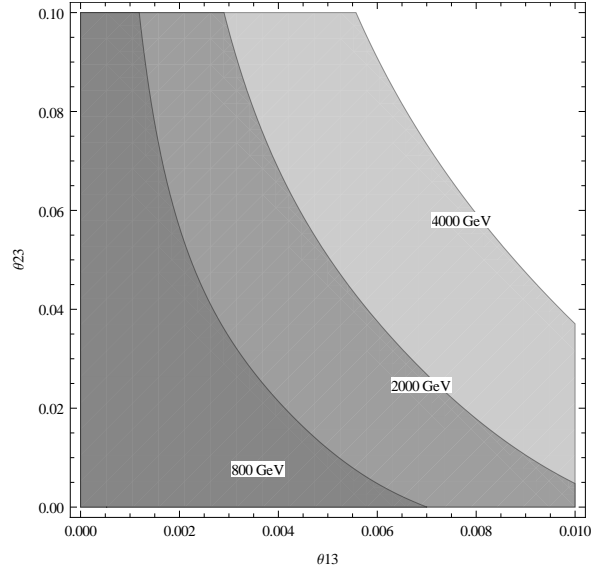


Figure 3: Bounds from $\mu \rightarrow eee$ in the $\theta_{13} - \theta_{23}, \theta_{23}$ plane using $m_{Z'}(800, 2000, 4000)$ GeV.

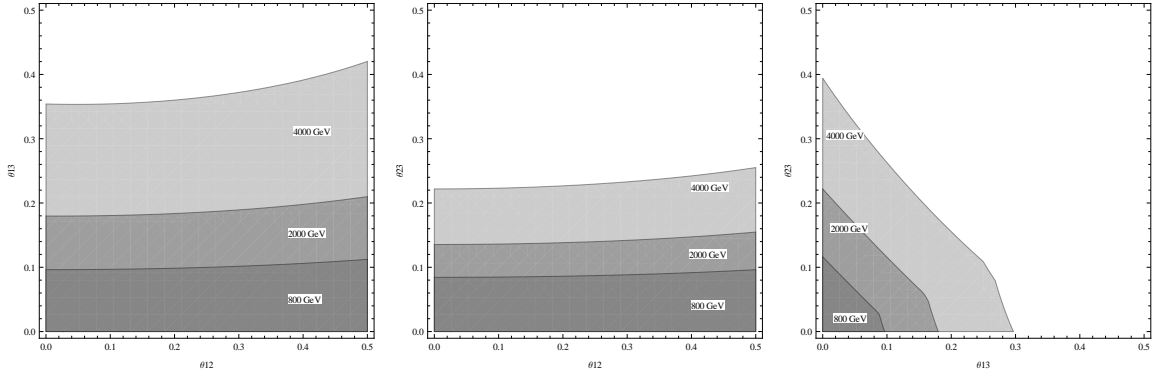


Figure 4: Bounds obtained using the $\tau \rightarrow lll$ processes of table 1, with the three different scenarios described in section 3 for θ_{12}, θ_{13} , and θ_{23} with $m_{Z'}(800, 2000, 4000)$ GeV.

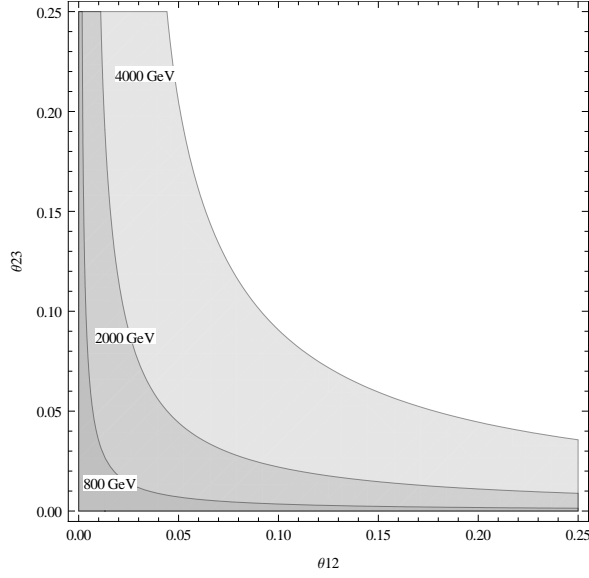


Figure 5: Bounds from $\tau \rightarrow \mu\gamma$ in the $\theta_{12} - \theta_{23}$ plane with $m_{Z'}(800, 2000, 4000)$ GeV.

model described in section 2. For the first case (where the first leptonic family is in the different representation), we obtained allowed regions on the $\theta_{12} - \theta_{23}$ plane of the order of $\sim 10^{-1}$. For the second case (the third leptonic family in a different representation), the bound on the process $\mu \rightarrow e\gamma$ constrain the space of parameters to regions around $\theta_{12} \sim 10^{-2}$, $\theta_{23} \sim 10^{-2}$ and $\theta_{13} \sim 10^{-3}$. We also explored the bounds coming from other LFV processes, which are consistent with these regions and the results are shown in figures 2-5.

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References

- [1] F. Pisano and V. Pleitez, Phys. Rev. D **46** (1992) 410 [arXiv:9206242]; P. H. Frampton, Phys. Rev. Lett. **69** (1992) 2889; J. C. Montero, F. Pisano and V. Pleitez, Phys. Rev. D **47** (1993) 2918 [arXiv:9212271]; R. Foot, O. F. Hernandez, F. Pisano and V. Pleitez, Phys. Rev. D **47** (1993) 4158 [arXiv:9207264]. R. Foot, L. N. Hoang and T. A. Tran, Phys. Rev. D **50**, 34 (1994) [arXiv:9402243]; J. T. Liu and D. Ng, Phys. Rev. D **50**, 548 (1994) [arXiv:9401228]; J. T. Liu, Phys. Rev. D **50**, 542 (1994) [arXiv:9312312]; R. Foot, O. F. Hernandez, F. Pisano and V. Pleitez, Phys. Rev. D **47**, 4158 (1993) [arXiv:9207264]. M. B. Tully and G. C. Joshi, Phys. Rev. D **64** (2001) 011301 [arXiv:0011172].
- [2] F. Pisano and V. Pleitez, arXiv:hep-ph/9307265; J. Alexis. Rodriguez and M. Sher, Phys. Rev. D **70** (2004) 117702, [arXiv:0407248]; A. E. Carcamo Hernandez, R. Martinez and F. Ochoa, Phys.

- Rev. D **73** (2006) 035007 [arXiv:0510421] ; J. M. Cabarcas, D. Gomez Dumm and R. Martinez, J. Phys. G **37** (2010) 045001 [arXiv:0910.5700]; M. A. Perez, G. Tavares-Velasco and J. J. Toscano, Phys. Rev. D **69**, 115004 (2004) [arXiv:0402156]. J. M. Cabarcas, J. Duarte and J-A. Rodriguez, Adv. High Energy Phys. **2012**, 657582 (2012) [arXiv:1111.0315 [hep-ph]]. R. H. Benavides, Y. Giraldo and W. A. Ponce, Phys. Rev. D **80** (2009) 113009 [arXiv:0911.3568 [hep-ph]].
- [3] I. Cortes Maldonado, A. Moyotl and G. Tavares-Velasco, Int. J. Mod. Phys. A **26**, 4171 (2011) [arXiv:1109.0661 [hep-ph]]. E. Nardi, arXiv:1112.4418 [hep-ph]. J. I. Aranda, J. Montano, F. Ramirez-Zavaleta, J. J. Toscano and E. S. Tututi, arXiv:1202.6288 [hep-ph]. B. M. Dassinger, T. .Feldmann, T. .Mannel and S. Turczyk, JHEP **0710**, 039 (2007) [arXiv:0707.0988 [hep-ph]]. R. Benbrik, M. Chabab and G. Faisel, arXiv:1009.3886 [hep-ph].
- [4] M. Ahmed *et al.* [MEGA Collaboration], Phys. Rev. D **65**, 112002 (2002) [hep-ex/0111030].
- [5] O. Lychkovskiy and M. Vysotsky, J. Exp. Theor. Phys. **114**, 382 (2012) [arXiv:1010.1694 [hep-ph]].
- [6] T. A. Nguyen, N. A. Ky and L. N. Hoang, Int. J. Mod. Phys. A **15**, 283 (2000) [arXiv:9810273]; M. B. Tully and G. C. Joshi, Int. J. Mod. Phys. A **18**, 1573 (2003) [arXiv:9810282]; W. A. Ponce, Y. Giraldo and L. A. Sanchez, Phys. Rev. D **67**, 075001 (2003) [arXiv:0210026]; P. V. Dong, L. N. Hoang, D. T. Nhung and D. V. Soa, Phys. Rev. D **73**, 035004 (2006) [arXiv:0601046]. M. Ozer, Phys. Rev. D **54**, 1143 (1996).
- [7] G. C. Branco, M. N. Rebelo and J. I. Silva-Marcos, Phys. Lett. B **597** (2004) 155 [arXiv:hep-ph/0403016].
- [8] P. Langacker and M. Plumacher, Phys. Rev. D **62**, 013006 (2000) [hep-ph/0001204].
- [9] K. Hayasaka [Belle Collaboration], PoS ICHEP **2010**, 241 (2010) [arXiv:1011.6474 [hep-ex]]. K. Hayasaka et al. (Belle Collaboration), Phys. Lett. B 666, 18 (2008). [arXiv:1010.3746 [hep-ex]]. K. Hayasaka et al. (Belle Collaboration), Phys. Lett. B 687, 139 (2010).[arXiv:1001.3221 [hep-ex]]. Belle Collaboration. Y. Miyazaki et. al. Phys. Lett. B. 660 (2008). Babbar Collaboration. Phys. Rev. Lett. 92(121801).
- [10] B. Aubert et al. (BABAR Collaboration), Phys. Rev. Lett. 104, 021802 (2010). B. Aubert et al. (BaBar Collaboration), Phys. Rev. D 81, 111101 (2010).[arXiv:1002.4550 [hep-ex]].
- [11] B. Aubert et al. (BaBar Collaboration), arXiv:1202.3650 [hep-ex].
- [12] Y. Miyazaki, arXiv:1109.2377 [hep-ex].